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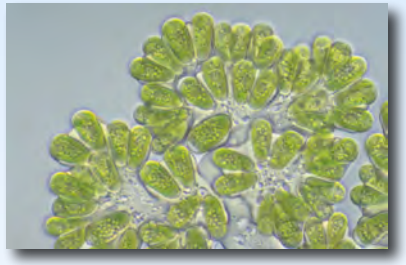
Routes to Carbon-Neutral Transportation Fuels Derived from Solar Energy: The Helios Approach

California Climate Change Conference
Sept 10, 2008

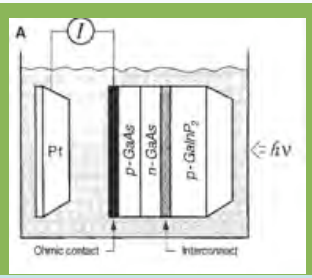
Crops & Biomass

Dr. Elaine Chandler
Helios Solar Energy Research Center
at
Lawrence Berkeley National Lab



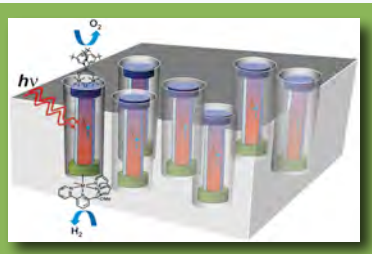
Oil-producing organisms

Nanotechnology and Chemical Systems that Mimic Nature



PEC apparatus

Activated membranes



Integrated PS systems

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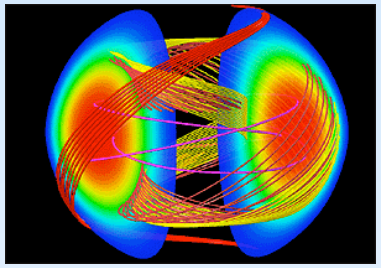
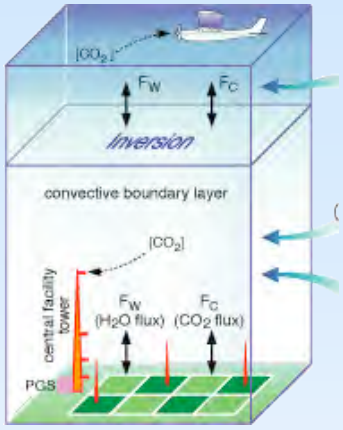
Energy Research @Berkeley Lab

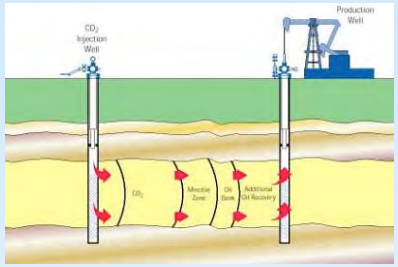


Fusion



Atmospheric studies

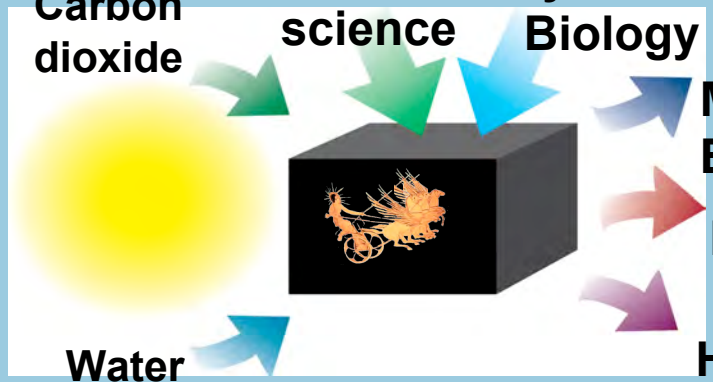
Geothermal



Fossil recovery & carbon sequestration

Building, Lighting, Home Appliance Standards

Helios

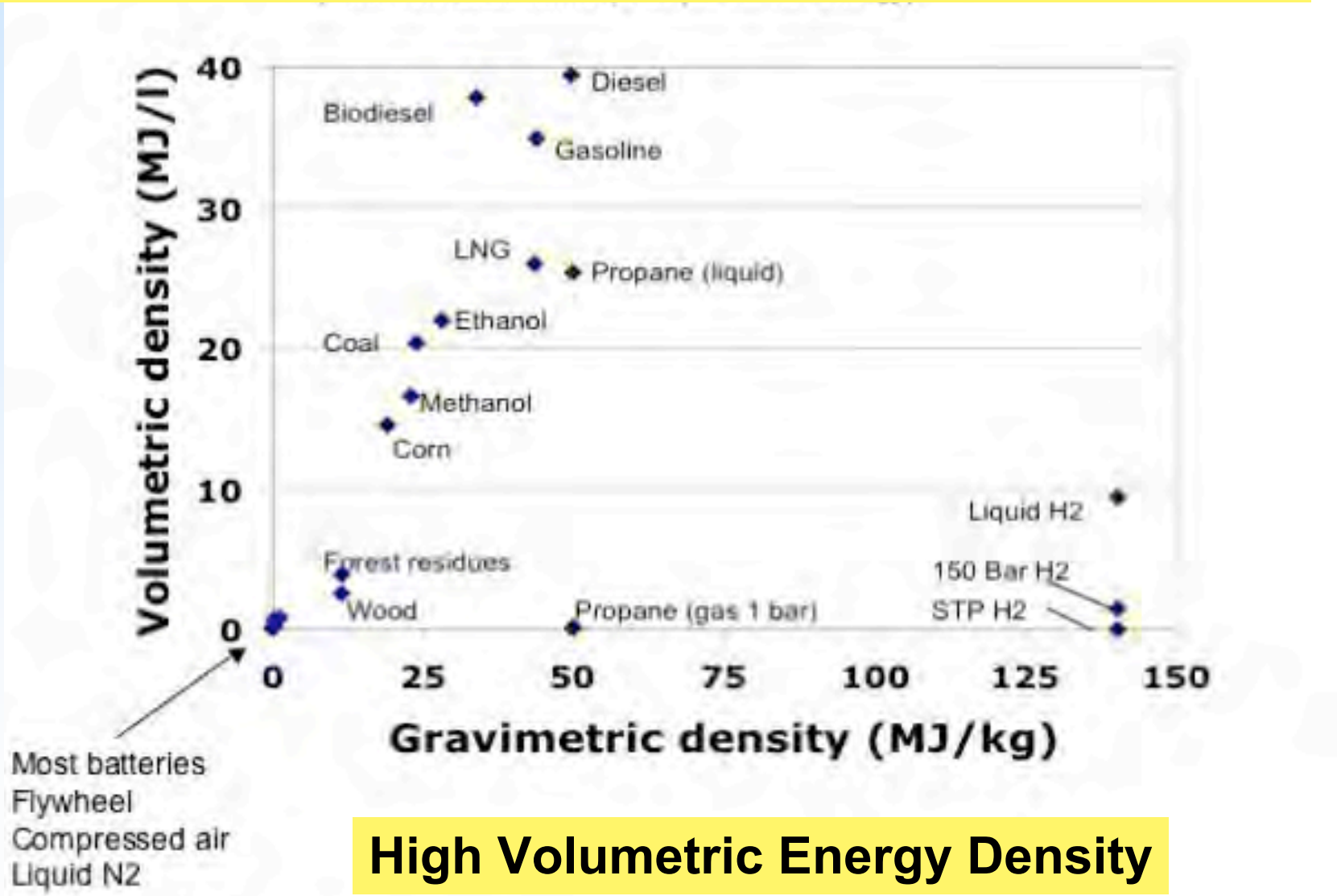


Goals of the Helios Initiative

- GOAL: Create transportation fuels from sunlight, 1% energy conversion efficiency, 10 year target

- Why? Transportation fuel is the most valuable type of stored energy

The reason we depend on the fossil fuels...



High Volumetric Energy Density

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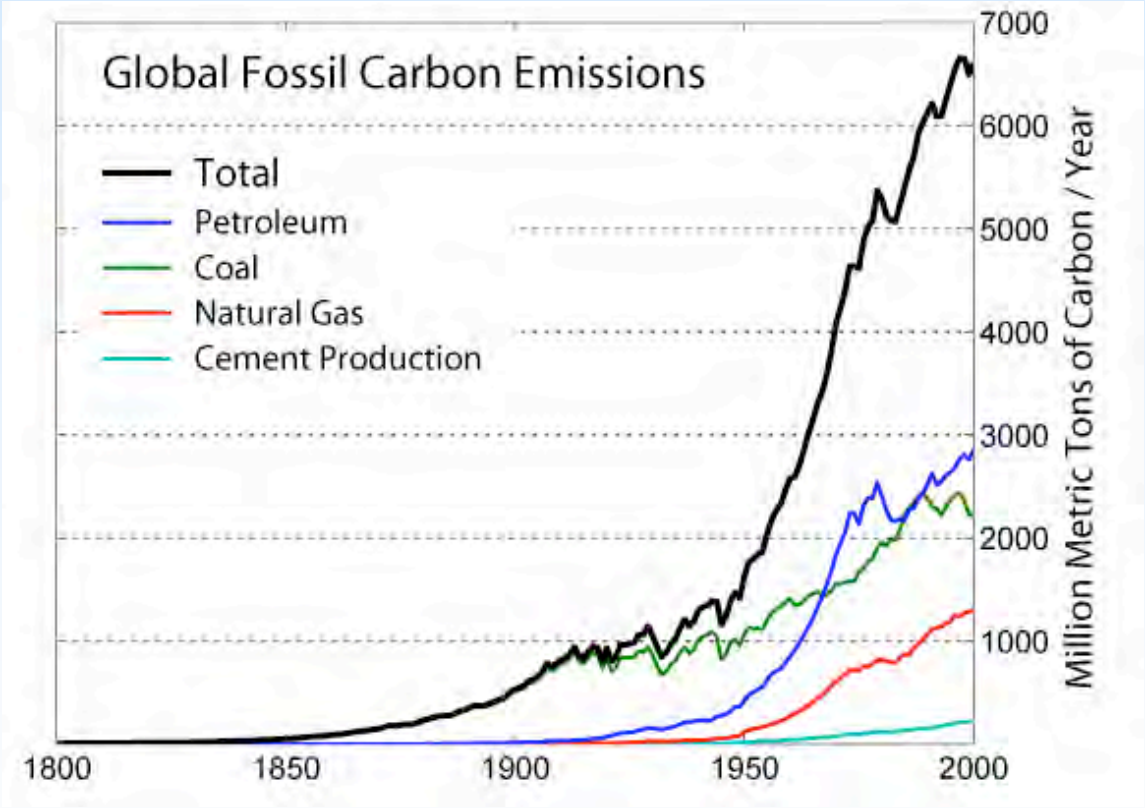
Carbon emissions from fossil fuels:

6-7 billion metric tons/year (2000)



Where does all the carbon go? Half of it stays in the atmosphere

Data from Carbon Dioxide Information Analysis Center, graphics by R. A. Rohde, Global Warming Art Project

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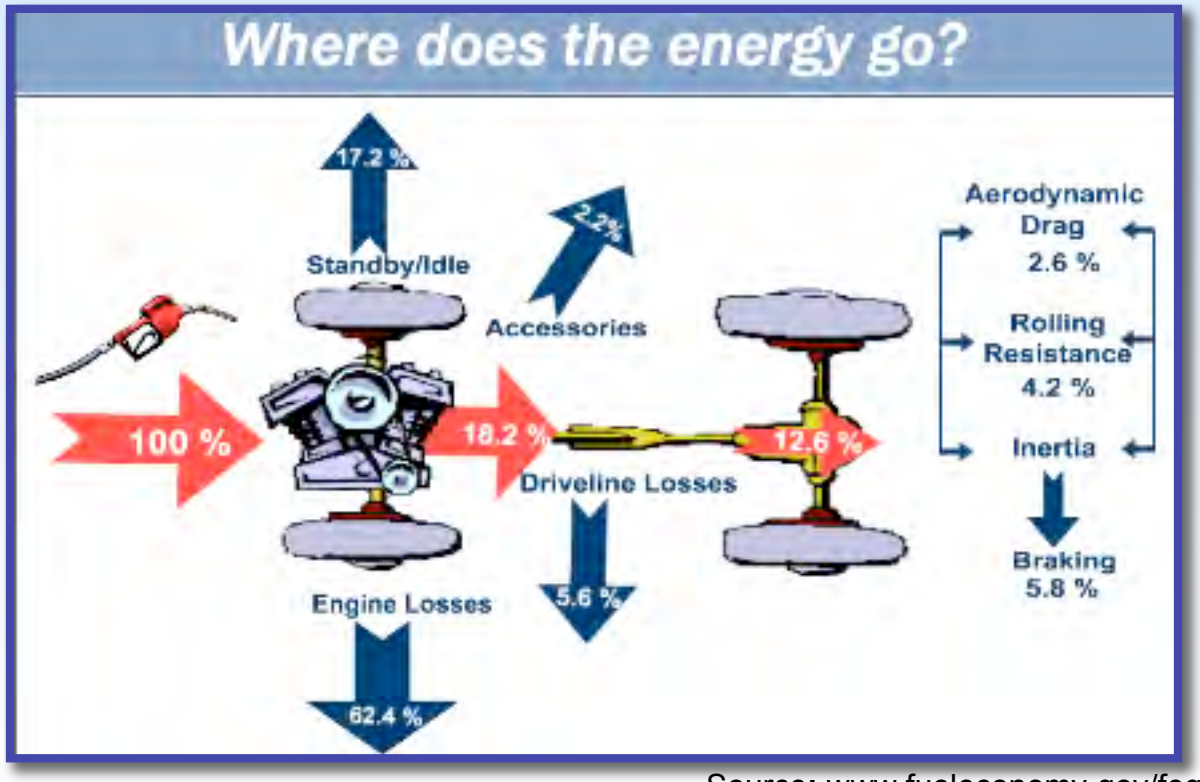
Better efficiency for our vehicles is an important step

Only 15% of the energy* in a gallon of gasoline is used effectively in a "modern" internal combustion engine vehicle

***2.5 cups equivalent**



Source: www.fueleconomy.gov/feg/atv.shtml

Improved efficiency will also help maximize the impact of carbon-neutral fuels

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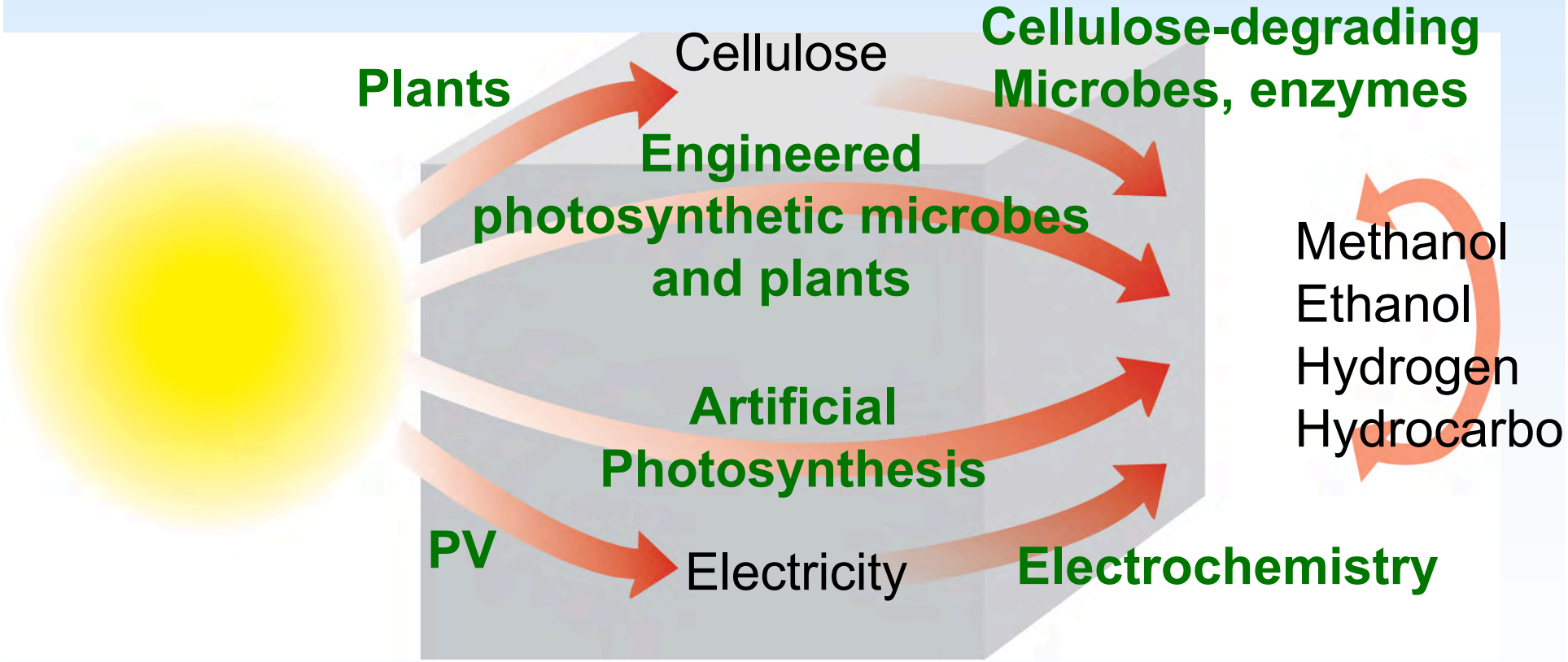
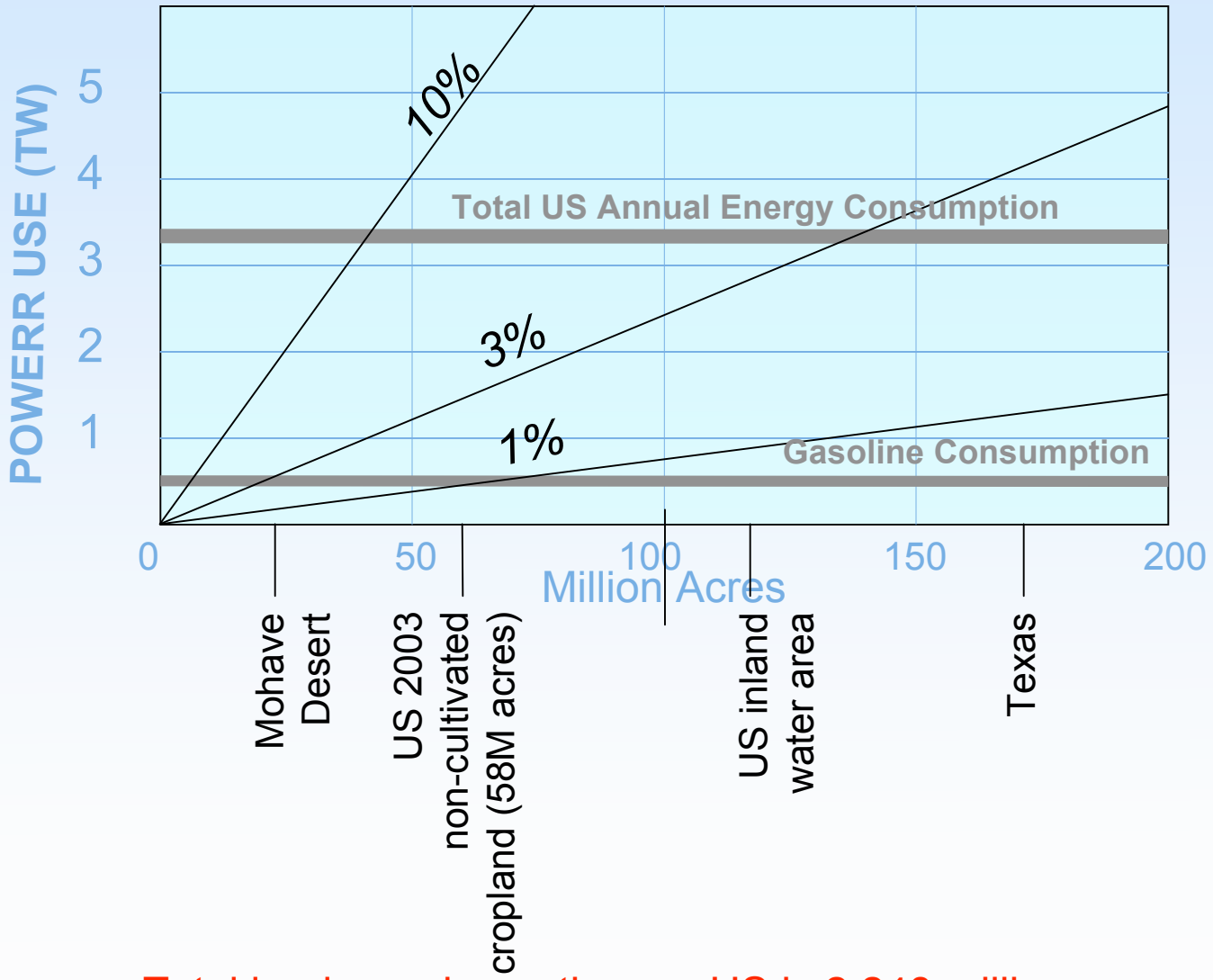
Helios paths to solar fuels



Solar Efficiency and Land Usage, USA



Total land area in contiguous US is 2,248 million acres

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Area requirements to satisfy all US electricity at 15% efficiency, fuel @1%

J.A. Turner, *Science* **285** 1999, p. 687.

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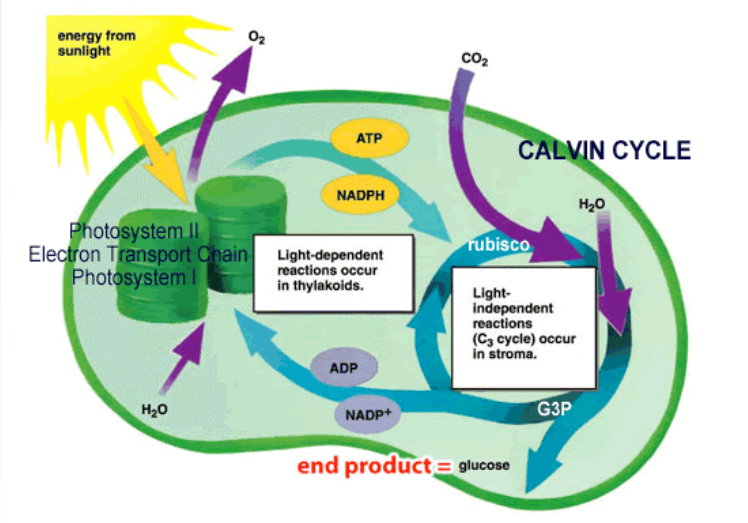
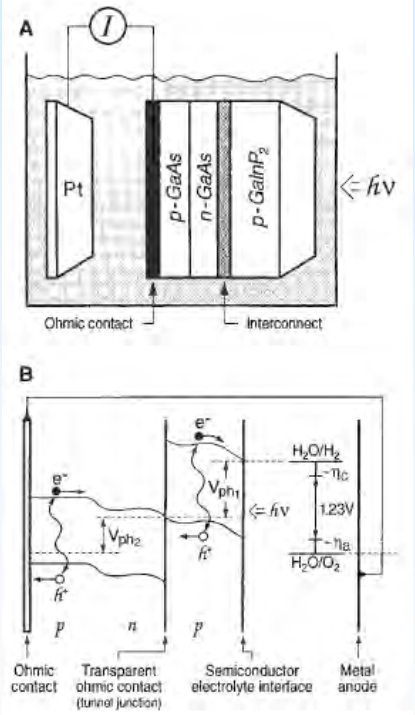
Development of solar-derived chemical fuel, efficient, scalable to the US needs, and at low cost

Photosynthesis



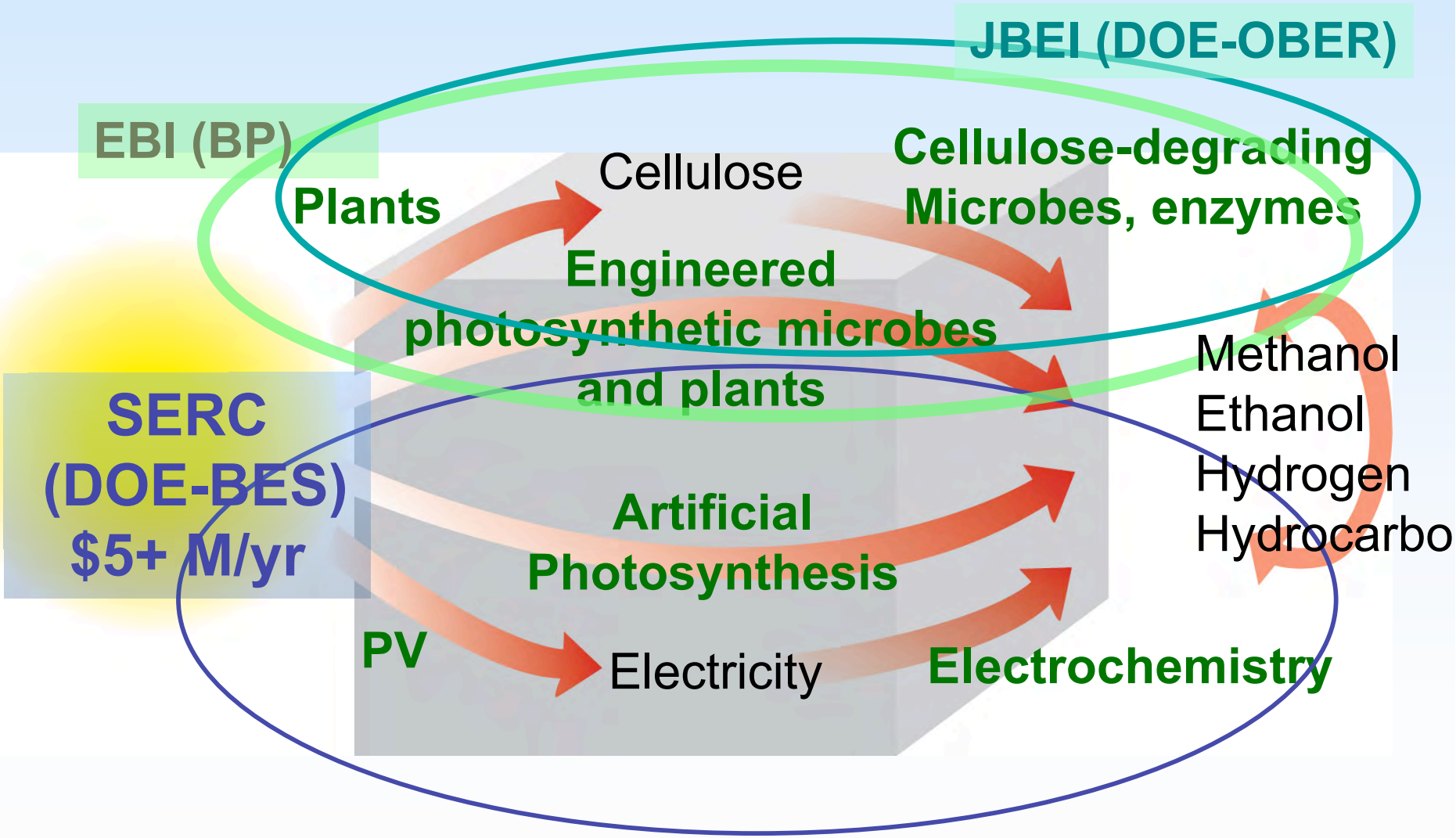
cheap but inefficient

Photoelectrochemical Device



efficient but expensive

Today Helios is 3 Projects Directed to One Goal: Carbon Neutral Chemical Fuel



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Energy Biosciences Institute

UC Berkeley, LBL, University of Illinois
Funded by a grant from BP

Focus on Biofuels

Feedstock Development

Biomass Depolymerization (Cell wall studies)

Biofuels Production

Fossil Fuel Bioprocessing

Environmental, Social & Economic Impact

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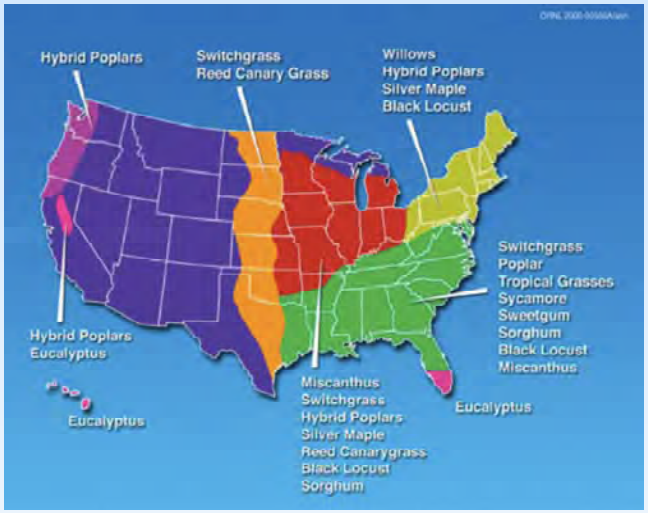
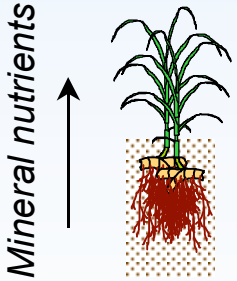
Feedstock Development

- Feedstock production
- Genetics and breeding
- Composition
- Stress
- Harvesting, transport and storage

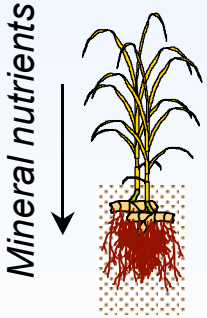


Spring/Summer



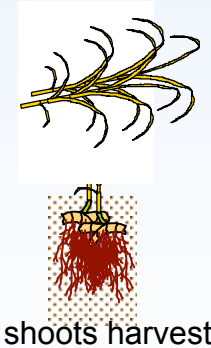
Translocation from rhizomes to growing shoot

Fall



Translocation to rhizomes as shoot senesces

Winter



Dry shoots harvested, nutrients stay in rhizomes

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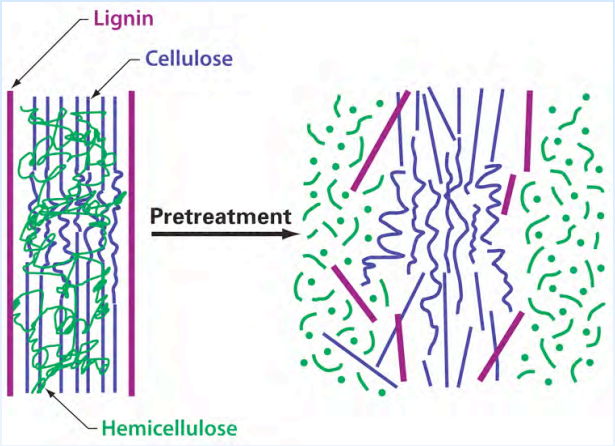
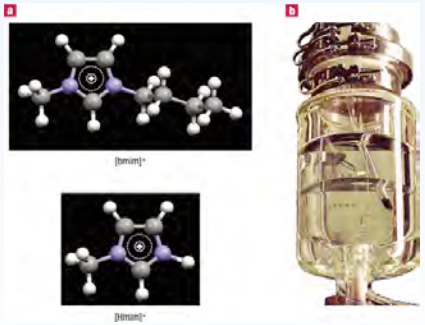
Biomass Depolymerization

- Pretreatment
- Enzyme discovery
- Chemical catalysis





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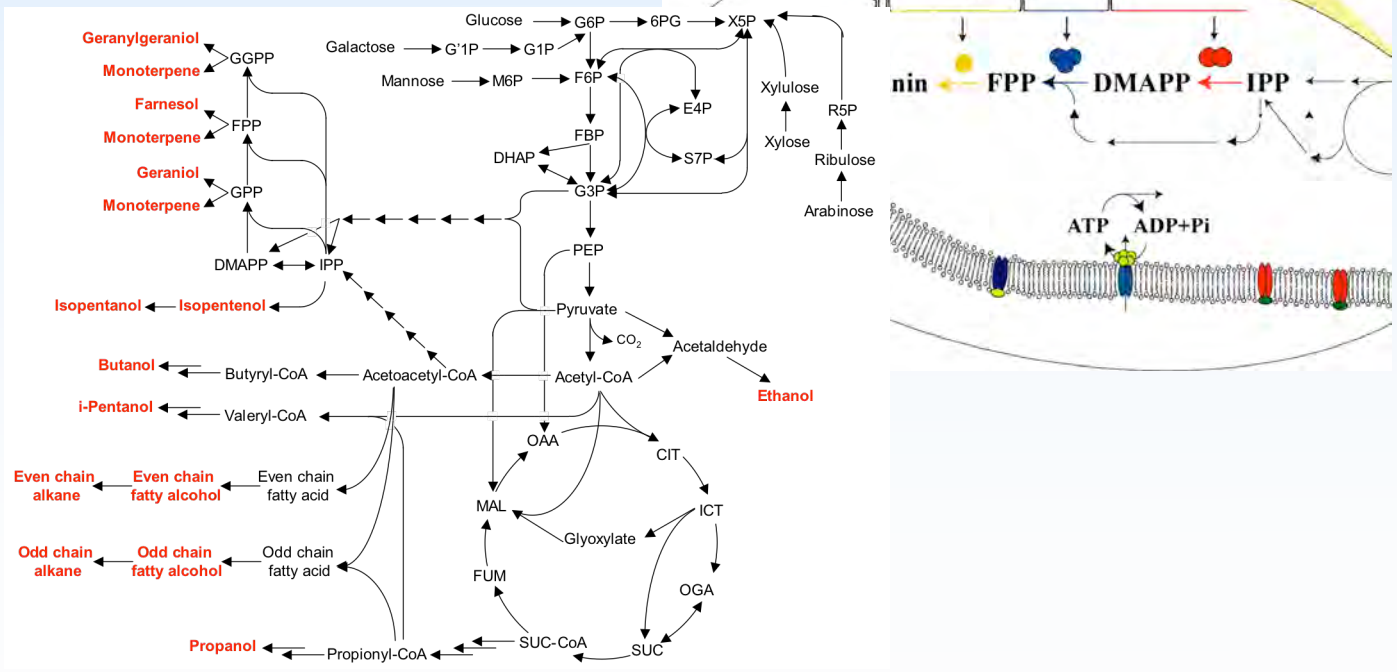
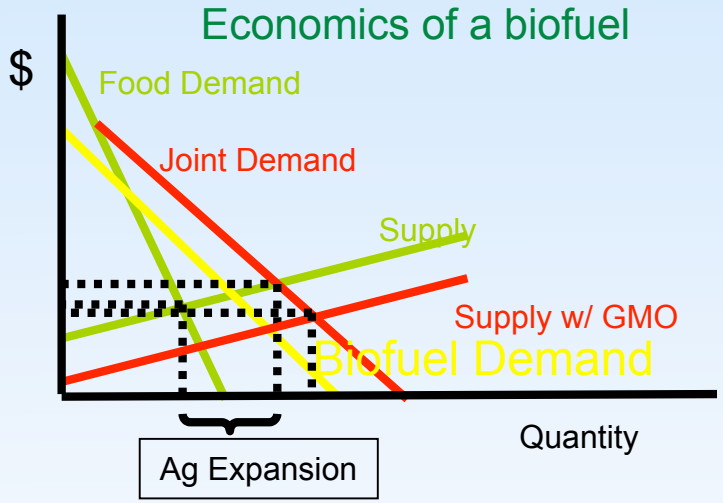
Biofuels Production

- Systems biology
- Pathway engineering
- Host engineering



Environmental, Social and Economic Dimensions

- Next-generation assessment
- Biofuels evaluation and adoption
- Biofuels markets and networks
- Social interactions and risks
- Environmental concerns

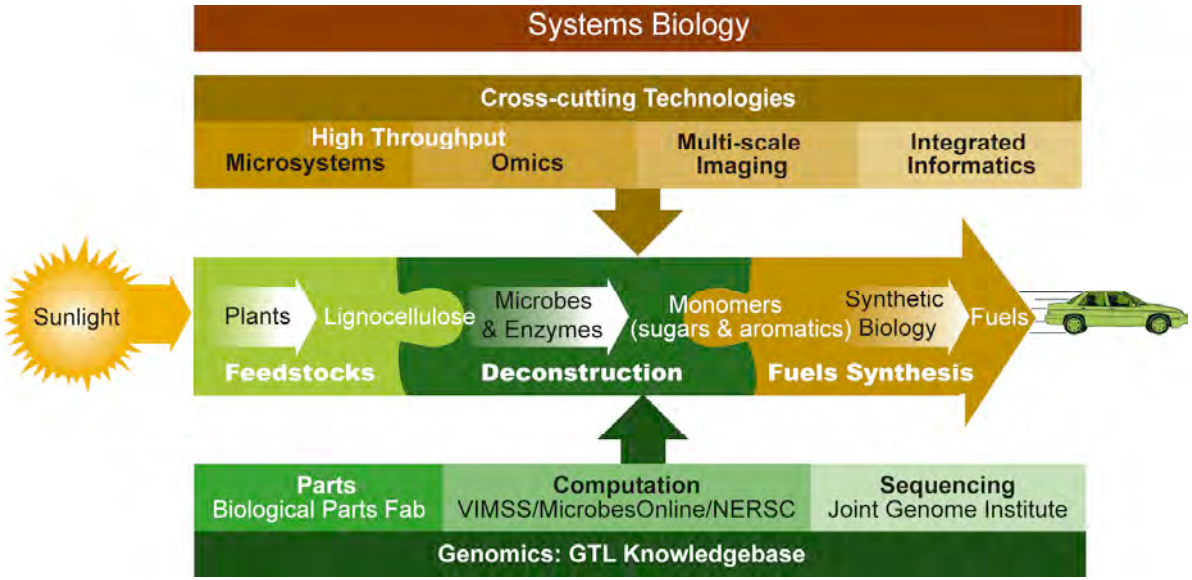


Areas of concern = Areas of research

-Displacement of food crops
-Scalability in agriculture
-Guarantee for farmers
-Investment in biorefineries
-Policy development

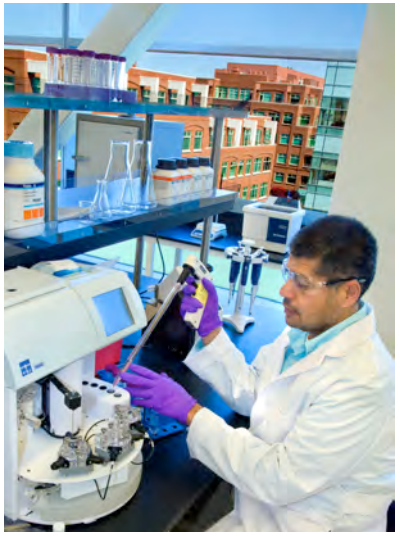
Joint BioEnergy Institute

An integrated approach



- **Partners**
  - LBNL
  - SNL
  - LLNL
  - UCB
  - UCD
  - Carnegie Institute

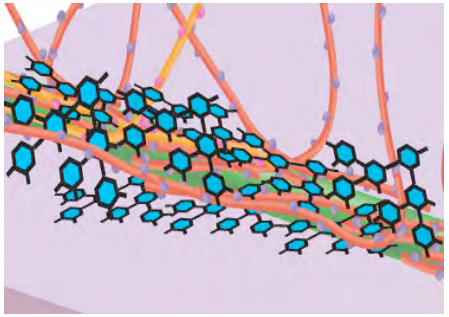
- **Single location**
- **Four divisions**
  - Feedstocks
  - Deconstruction
  - Fuels Synthesis
  - Technologies
- **www.jbei.org**



Lignin recalcitrance

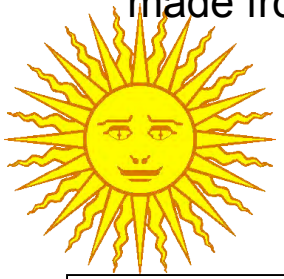
Challenges

- Lignin is recalcitrant to depolymerization
- Lignin occludes cellulose & hemicellulose
- Chemicals & fuels could be made from lignin

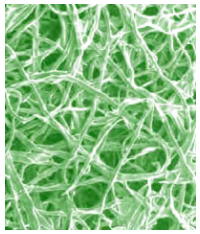


Approaches

- Engineer plants with cleavable lignin linkages
- Ionic liquids to separate cellulose and lignin
- Advanced imaging
- Ligno-chips to screen lignases

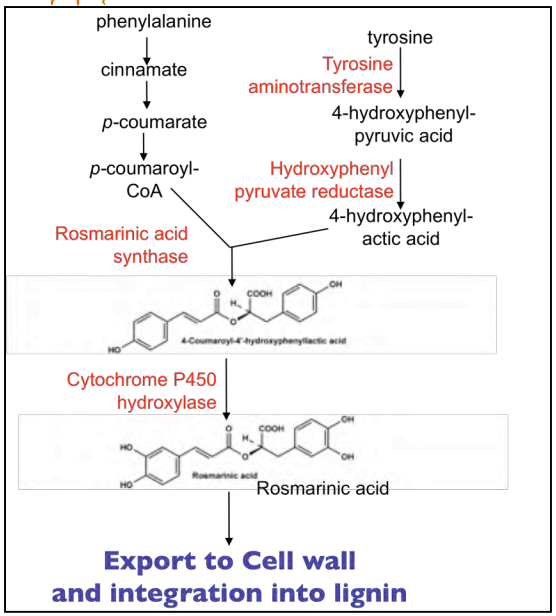


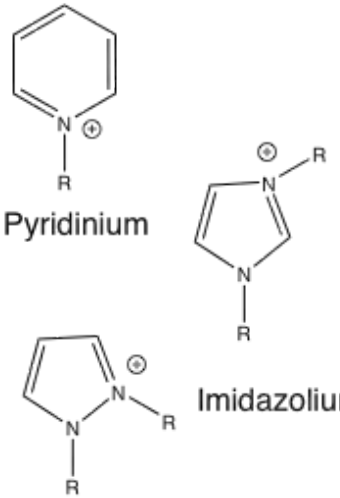
Feedstocks

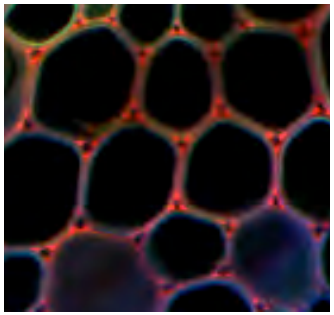


Deconstruction

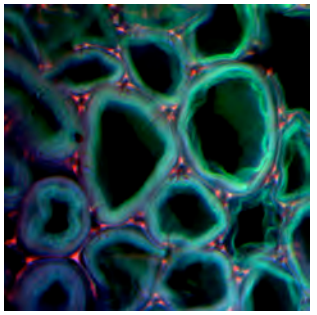
Fuel Synthesis

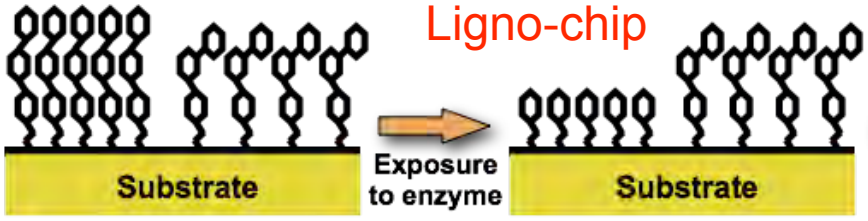






Ionic liquids

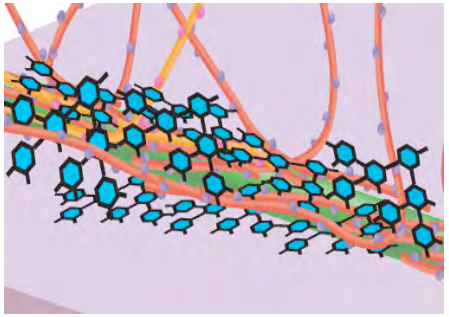




Fermentation inhibitors

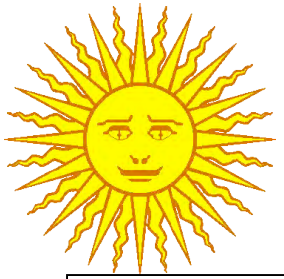
Challenges

- Functional groups on hemicellulose can inhibit fermentation
- Functional groups are not efficiently converted to fuels

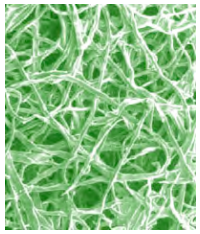


Approaches

- Engineer plants that do not have functional groups
- Ionic liquids to remove them
- Engineer microbes resistant to inhibitors
- Functional genomics

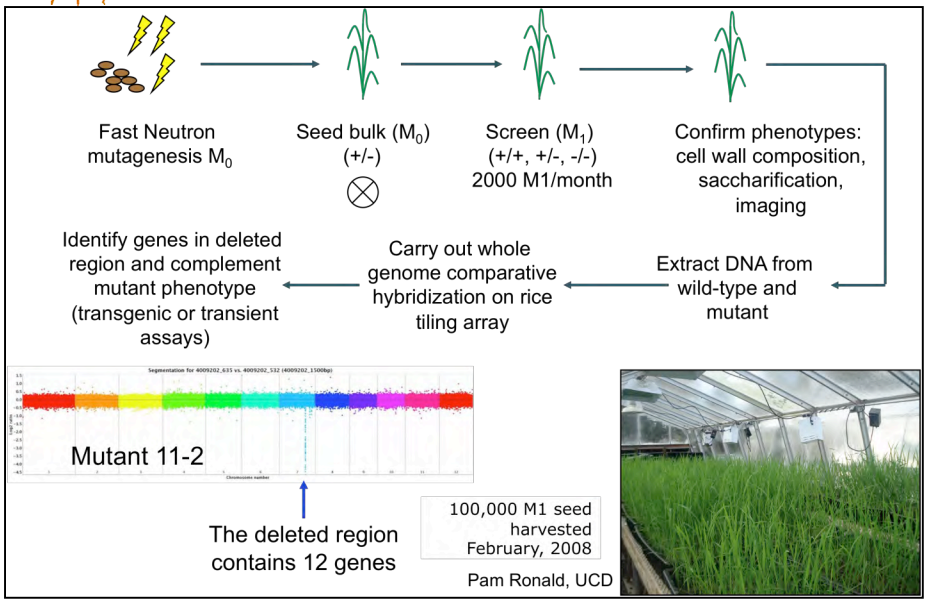


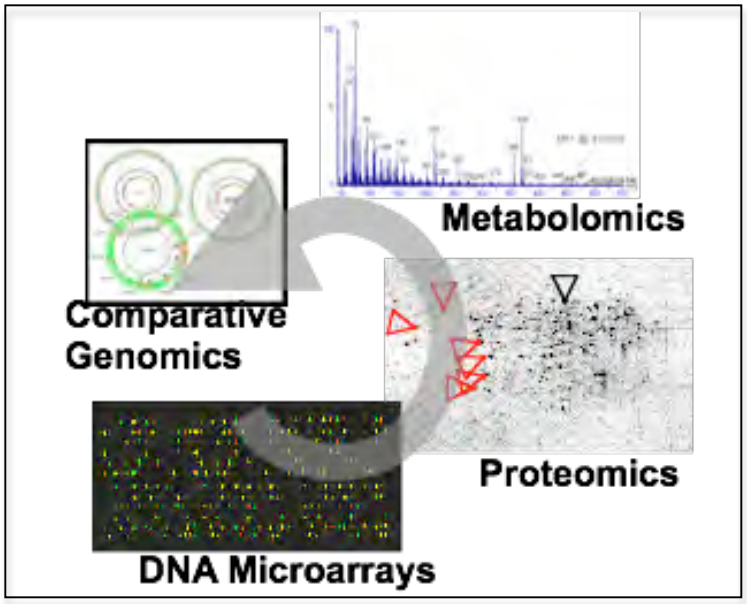
Feedstocks



Deconstruction

Fuel Synthesis





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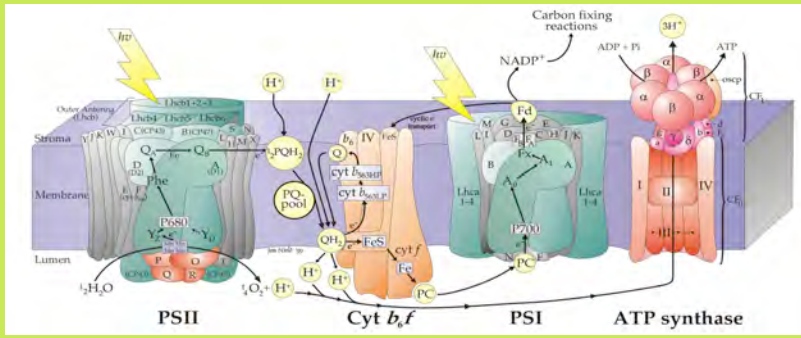
Artificial photosynthesis

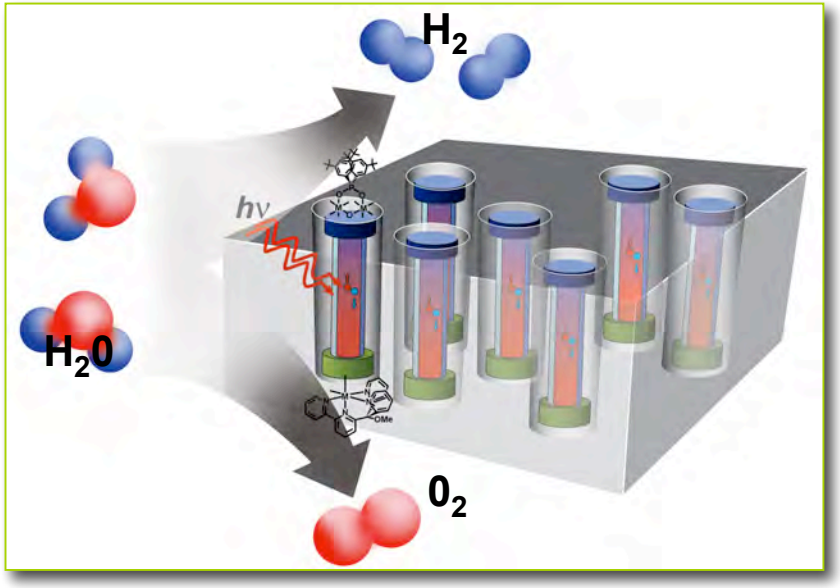
Actual photosynthetic apparatus



Courtesy of Freefoto.com

Researchers from LBNL, UC Berkeley, Cal Tech
Arizona State, UC San Diego

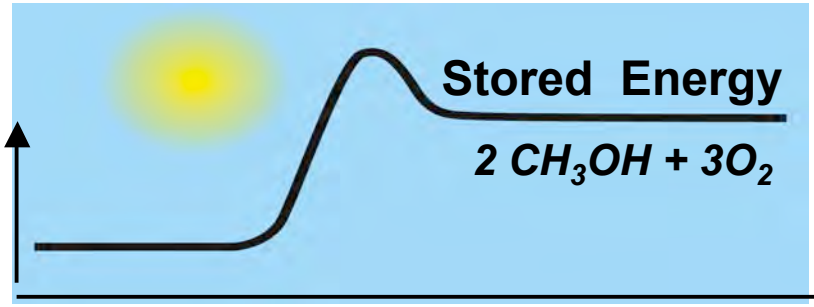
Artificial Photosynthesis



Funded by DOE Office of Basic Energy Sciences

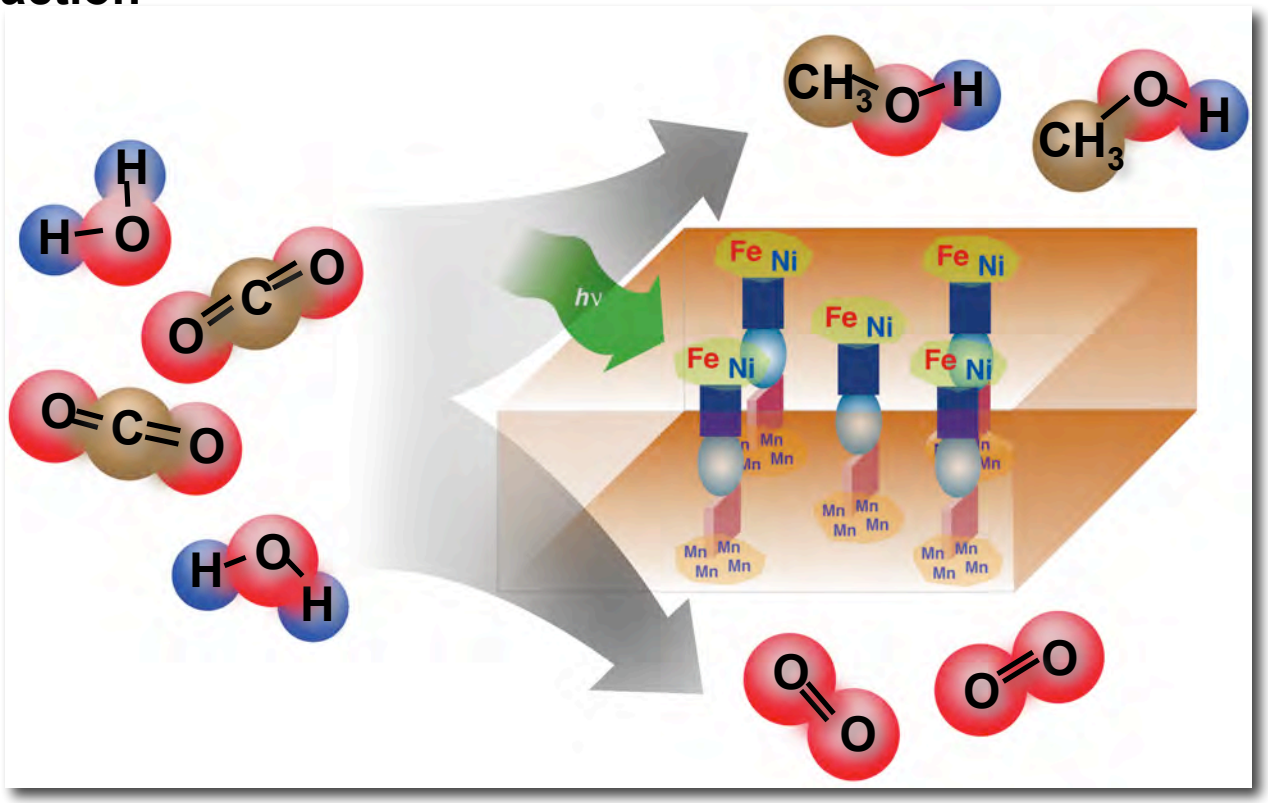
Solar Energy Research Center

Artificial photosynthesis



$$2\,CO_2 + 4\,H_2O \rightarrow 2\,CH_3OH + 3\,O_2$$

Fuel-Forming Reaction



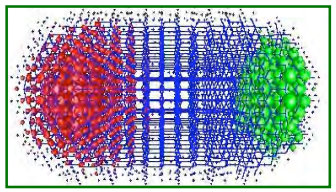
Solar Energy Research Center

Creating the parts for Artificial Photosynthesis

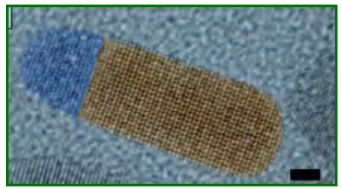
Direct transformation of sunlight to transportation fuel

Using DOE advances in nano materials, catalysis, photochemistry, and theory to develop renewable fuels

Nanoscale solar cells designed to drive catalytic reactions



Theory L-W Wang, LBNL

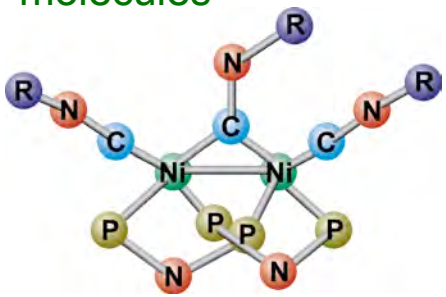


Synthesis P. Alivisatos, LBNL

System Goals

- **Scales to a size that impacts US fuel needs**
- **Made of inexpensive & durable components**
- **Reduces atmospheric carbon dioxide**

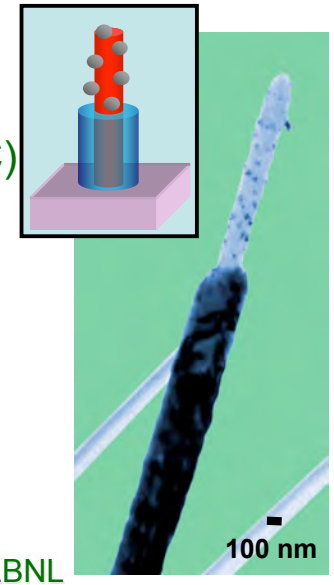
New catalytic molecules



For energy-storing reactions

C. Kubiac, UCSD

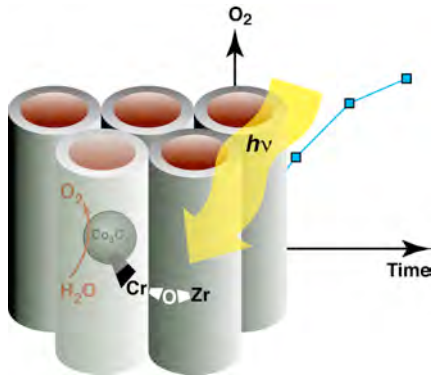
Entire solar photoelectro-catalysis (PEC) systems in single repeatable units



$Pt/Si/TiO_2$ (RuO2) Asymmetric Structure

P. Yang, LBNL

Membranes with embedded solar PEC systems



H. Frei, LBNL

We are now located throughout the East Bay

Helios Energy Research Facility (2010/11)

Wrapup

- Not “just” fascinating science
- 3 Different approaches to solar-based carbon-neutral fuels
- Near, mid, long term elements in these projects
- Dealing with scaling requirements, as well as societal issues